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Load alleviation on wind turbine blades using variable airfoil geometry

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LOAD ALLEVIATION ON WIND TURBINE BLADES USING VARIABLE AIRFOIL GEOMETRY

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Outline

- Motivation for the present work
- 2D computations
  - Tools
  - Main Results
- 3D computations
  - Tools
  - Main Results
- Wind tunnel testing
  - The model
  - Preliminary results
- Conclusions
- Future work

RISØ

Motivation for the work

- State of the art active load reduction employs pitching of whole wing
- Reductions of fatigue loads of up to 28% have been predicted
- But… Very long flexible blades may keep us from pitching fast enough to further reduce fatigue loads

- What if much faster load control could be possible?
- What if local load control on the blade could be possible?

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- State of the art active load reduction employs pitching of whole wing
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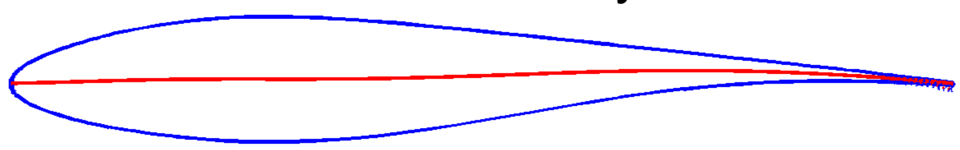
- What if much faster load control could be possible?
- What if local load control on the blade could be possible?

- Inspiration: Mother nature

- Idea: Use adaptive trailing edge geometry

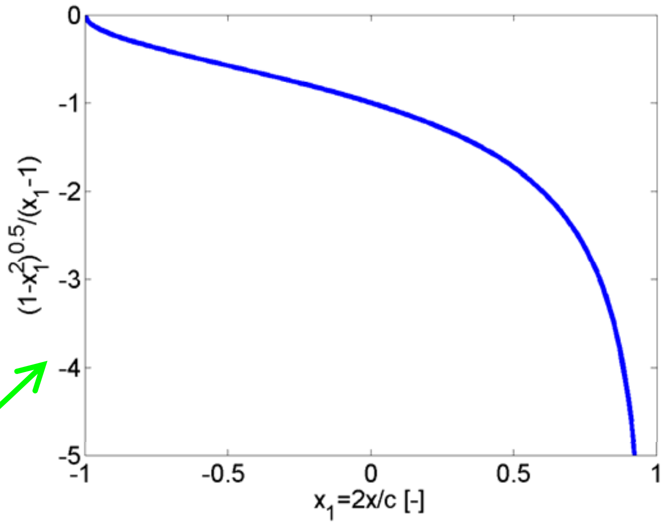
But why at the trailing edge?

- Potential thin-airfoil theory:

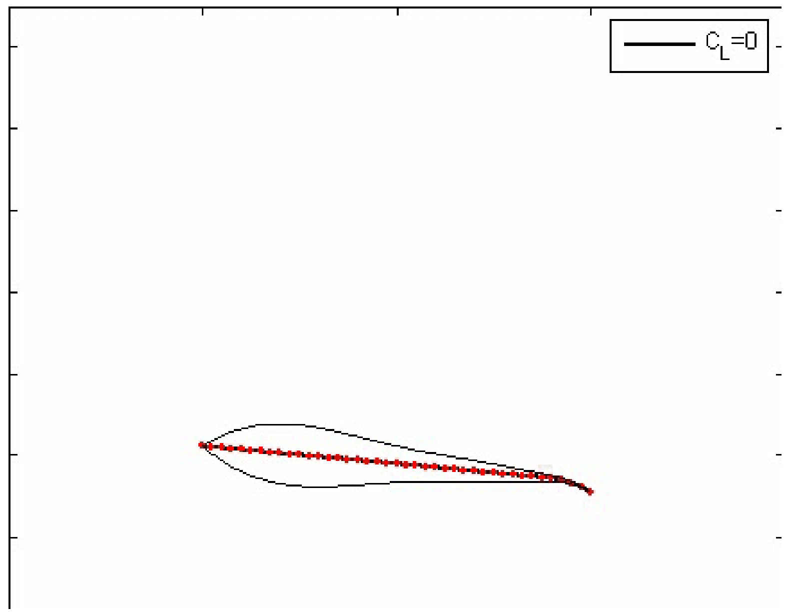


#1: Maximize bang for bucks

$$C_L = 2\int_{-1}^{1} \frac{\partial y}{\partial x}(x_1)\,\frac{\sqrt{1-x_1^{\,2}}}{x_1-1}\,dx_1$$



#2: Low loads at TE…
Both steady and unsteady.



RISØ

..And why not just a rigid flap?

- Surface discontinuity triggers stall

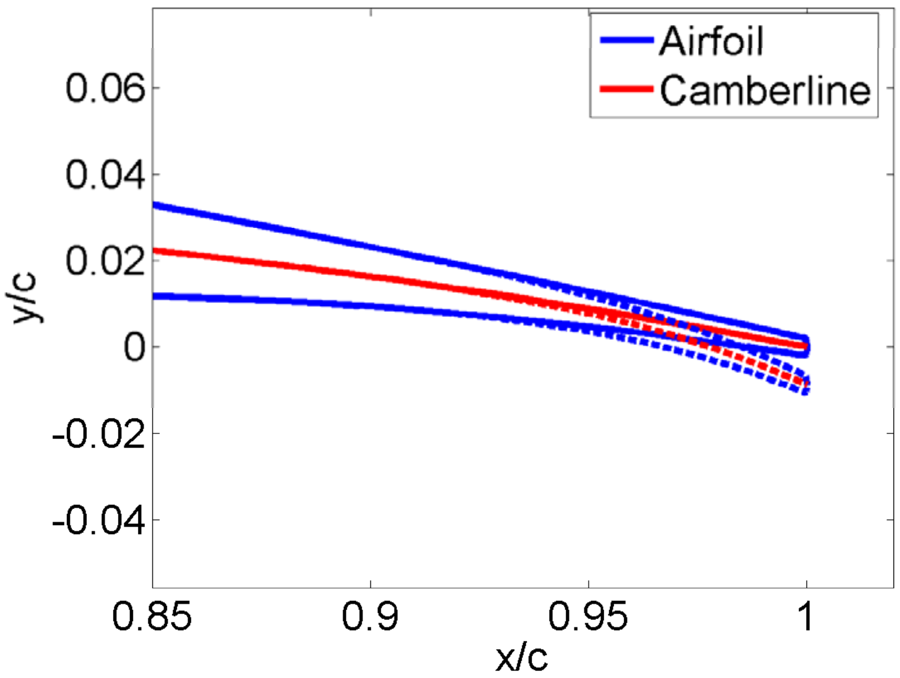
$\Downarrow$

- Noise issues
- Bad L/D leading to loss in power production
- Flap losing it's potential load reduction effect

$\Downarrow$

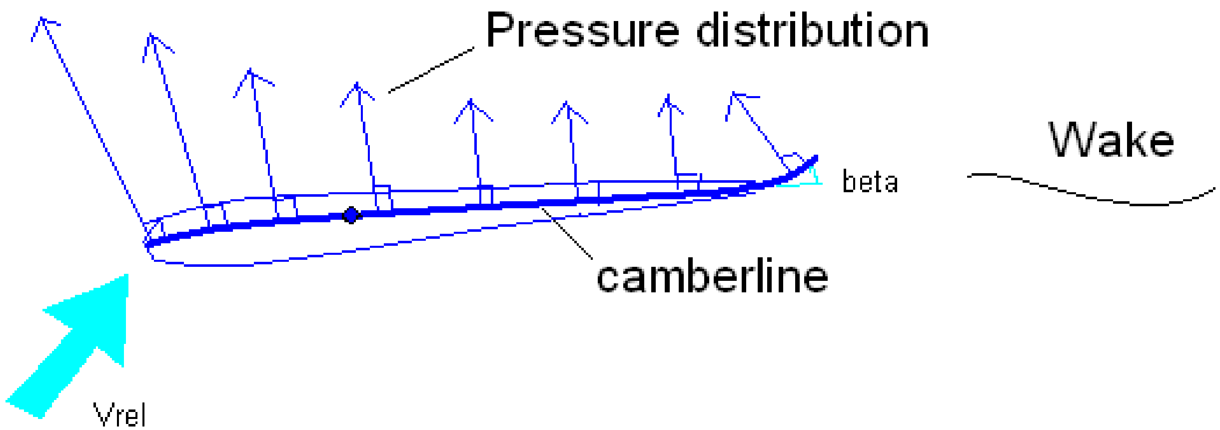
- Go for the continuously deforming one!

For everything shown here a 10% flap with limits: -5°>β>5° was used



2D: The tools

- **Aerodynamics**: Unsteady thin airfoil theory (potential flow) developed
  - Modal expansion of the airfoil deflections
  - Unsteady terms associated with wake modelled by the computationally efficient indicial method
  - Model capable of predicting integral as well as local aerodynamic forces
  - Good agreement with attached flow CFD



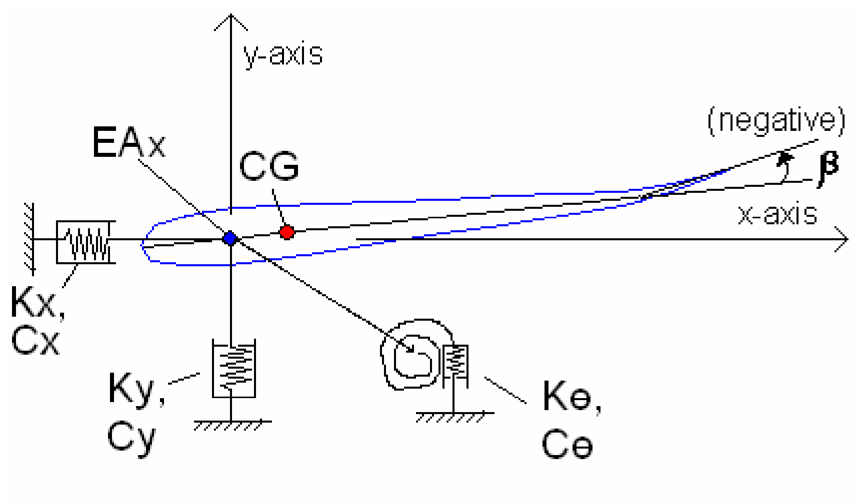
2D: The tools

- Structural model:

  Solid body

  + forces from TE

  deformation



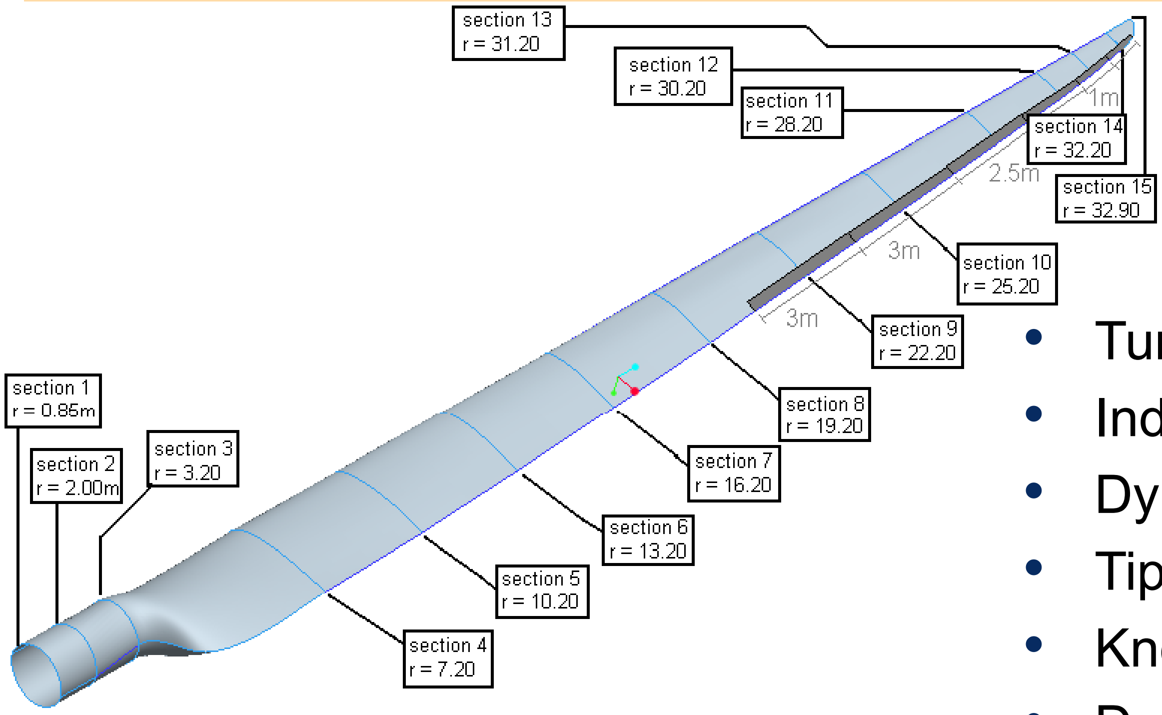
- Control: Simple PID control using flapwise deflection as input

2D animation.avi

2D: Main results

- Huge potential fatigue load reduction (~80% reduction of std(N))
- Low time lag essential
- Fast actuation velocity essential
- Trade-off to pitch DOF: Higher fatigue load in torsional direction.

3D model



AERODYNAMIC

- Turbulent wind series (Veers)
- Induced velocity (Bramwell)
- Dynamic inflow model (TUDk)
- Tip-loss factor (Prandtl)
- Known static lift and drag
- Dynamic flow (Gaunaa)

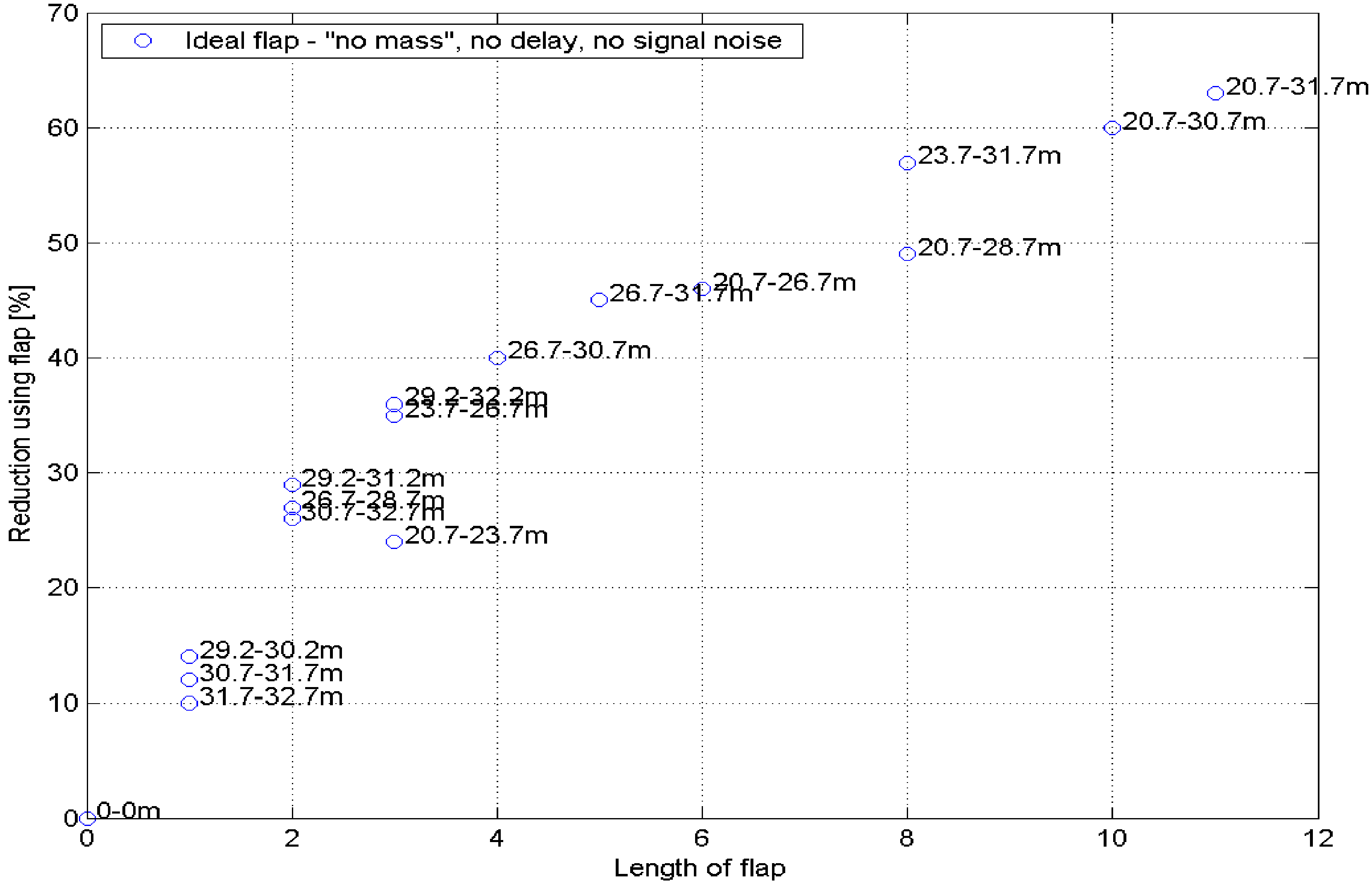
STRUCTURAL

- Slender cantilever beam theory
- Blade length 33m
- Known structural data
- Mode shapes and eigenfreq. 1f,2f,3f,4f,1e,2e,1Θ,2Θ

CONTROL

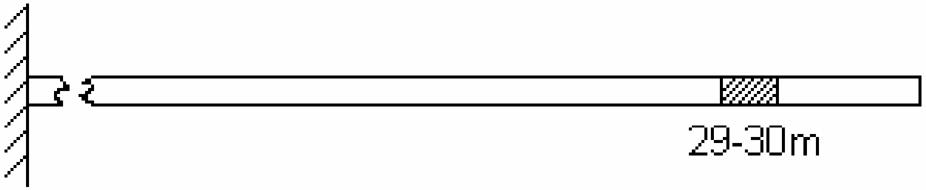
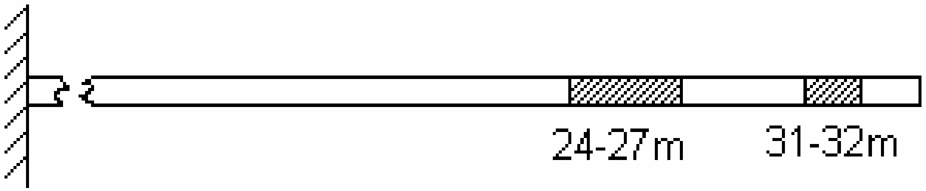
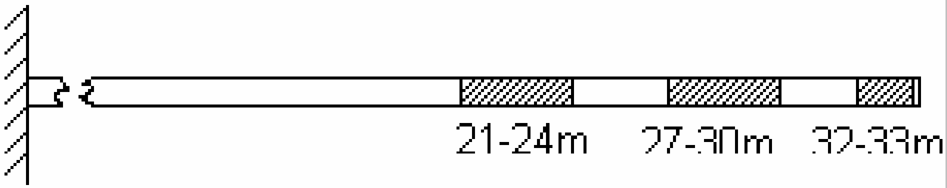
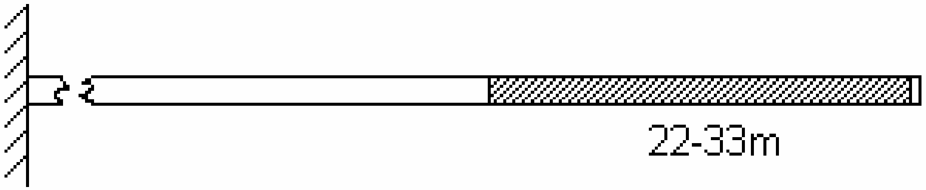
- Local PID's on flapwise deflection
- Parameters determined using optimization. min(eq. flapw. root mom.)

3D Results (1)

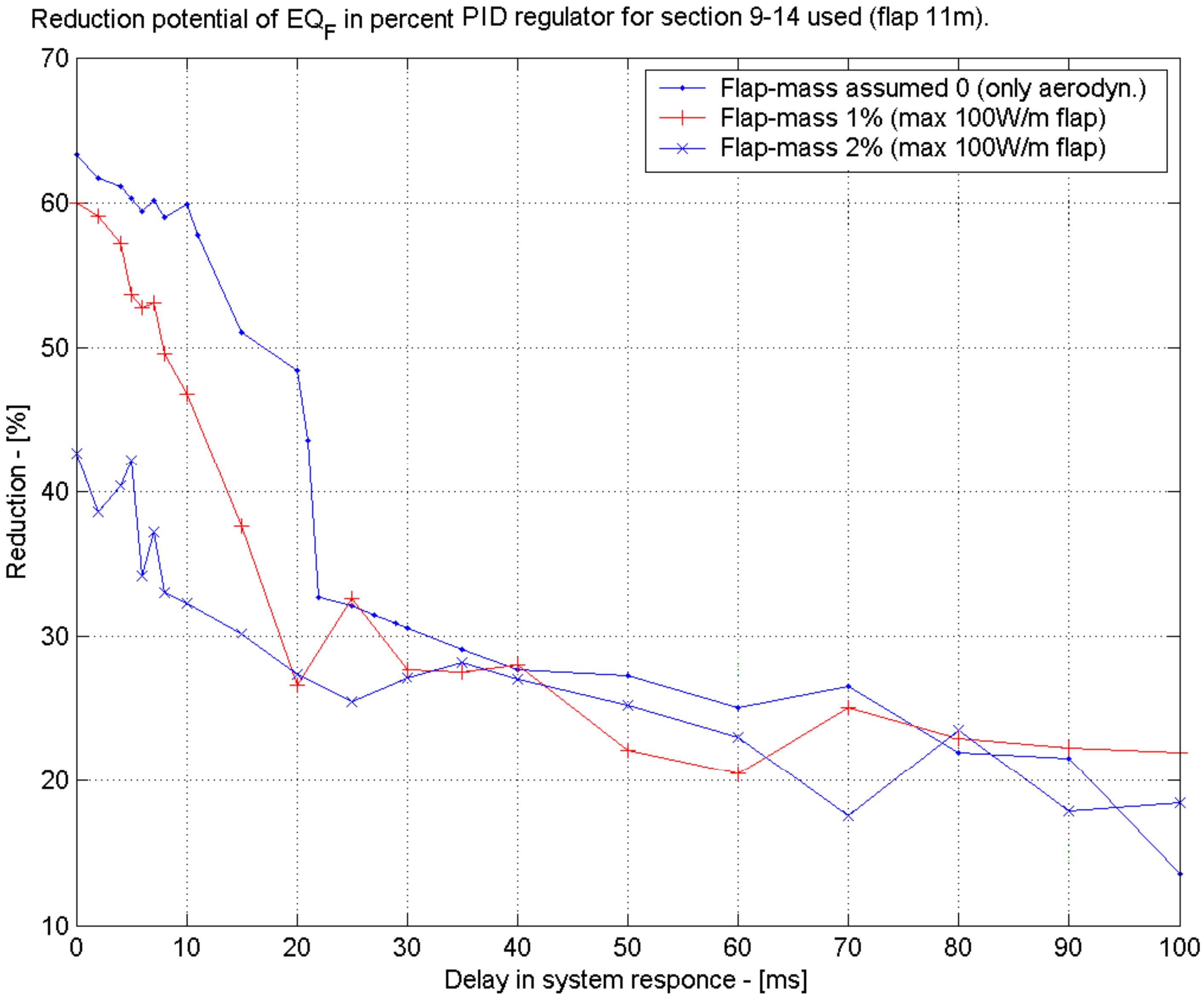


Ideal flap - "no mass", no delay, no signal noise
20.7-31.7m
20.7-30.7m
23.7-31.7m
20.7-28.7m
20.7-26.7m
26.7-31.7m
26.7-30.7m
29.2-32.2m
23.7-26.7m
29.2-31.2m
26.7-28.7m
30.7-32.7m
20.7-23.7m
29.2-30.2m
30.7-31.7m
31.7-32.7m
0-0m
Reduction using flap [%]
Length of flap
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12

3D results (2)

given flap	best radial location of given flap	flapwise root moment - maximum reduction potential — fatigue
one meter flap available	 29-30m	14%
four meters flap available	 24-27m 31-32m	50%
seven meters of flap available	 21-24m 27-30m 32-33m	62%
eleven meters of flap available	 22-33m	65%

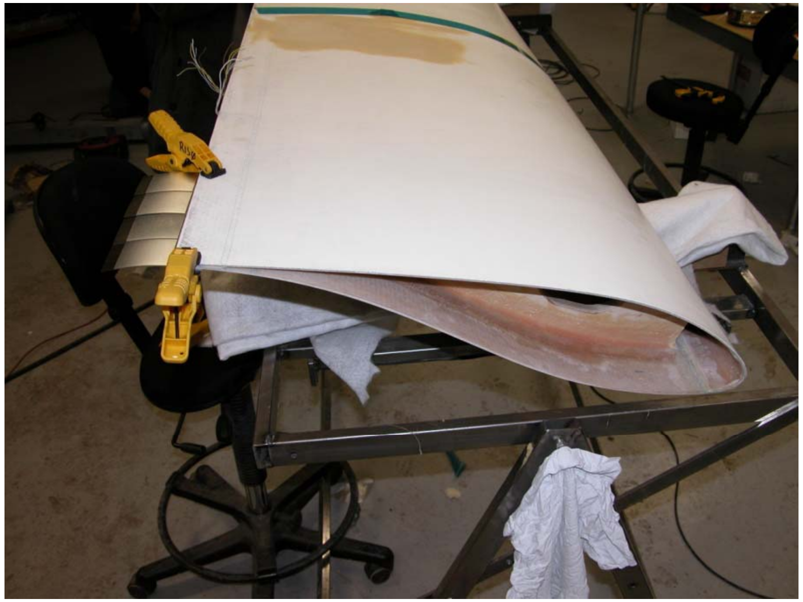
3D results (3)


Reduction potential of EQ_F in percent PID regulator for section 9-14 used (flap 11m).
Flap-mass assumed 0 (only aerodyn.)
Flap-mass 1% (max 100W/m flap)
Flap-mass 2% (max 100W/m flap)
Reduction - [%]
Delay in system responce - [ms]
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100

Wind Tunnel Testing

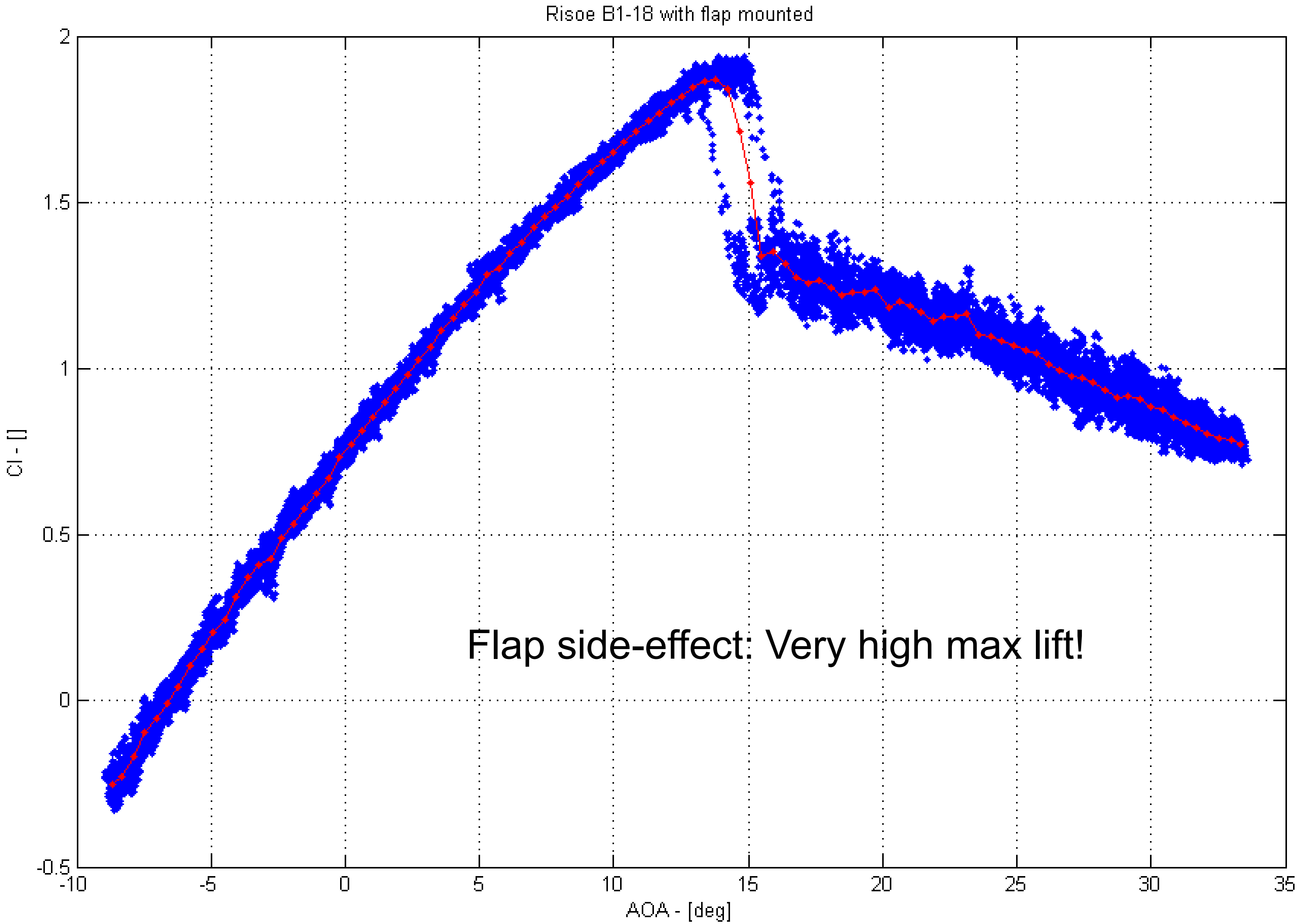
- The Actuator (piezo-electric)

- The Airfoil (Risø B1-18)

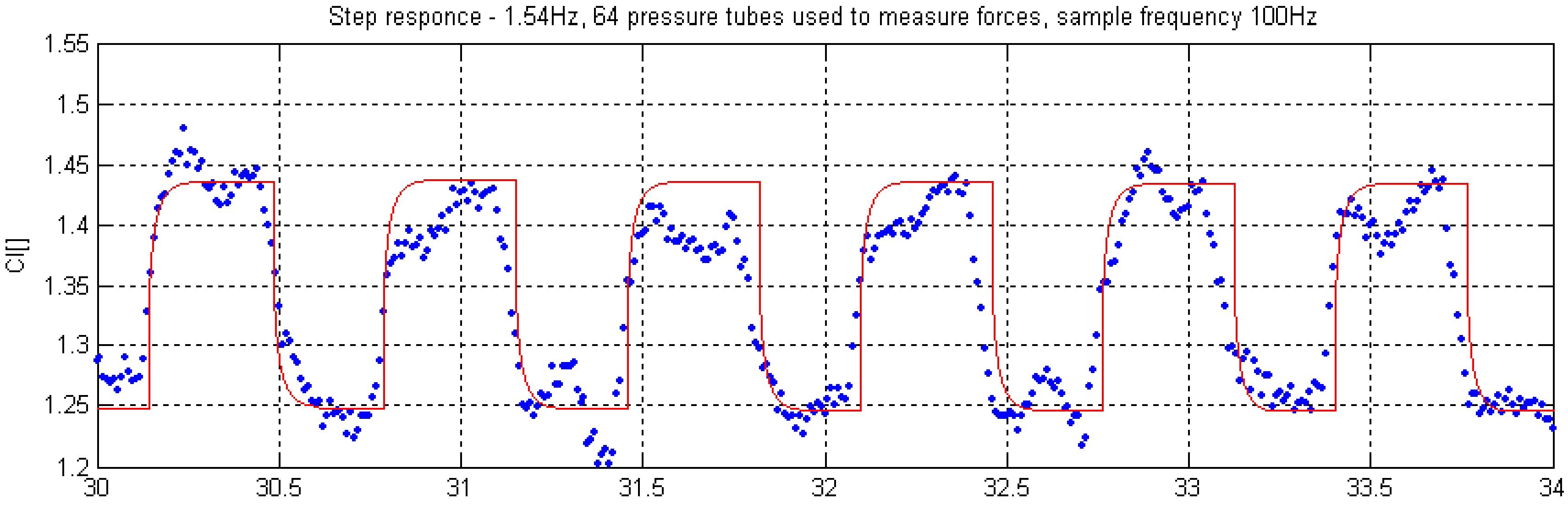


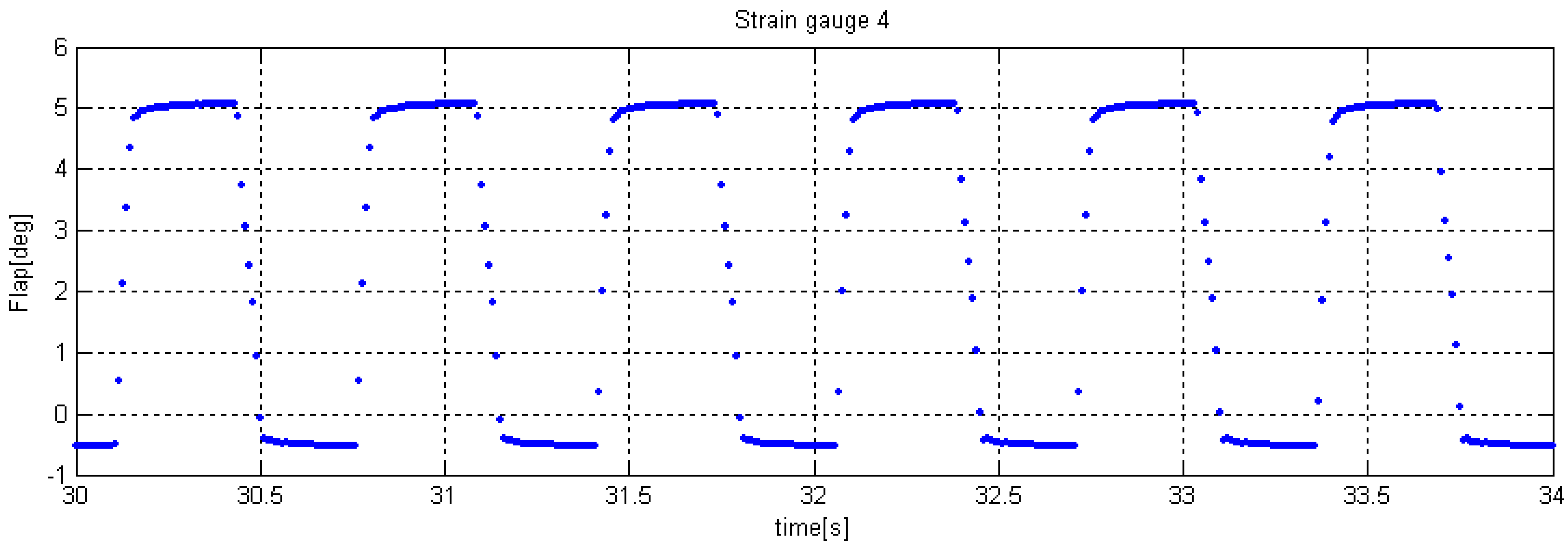
video from the wind tunnel.wmv

Preliminary result (steady)

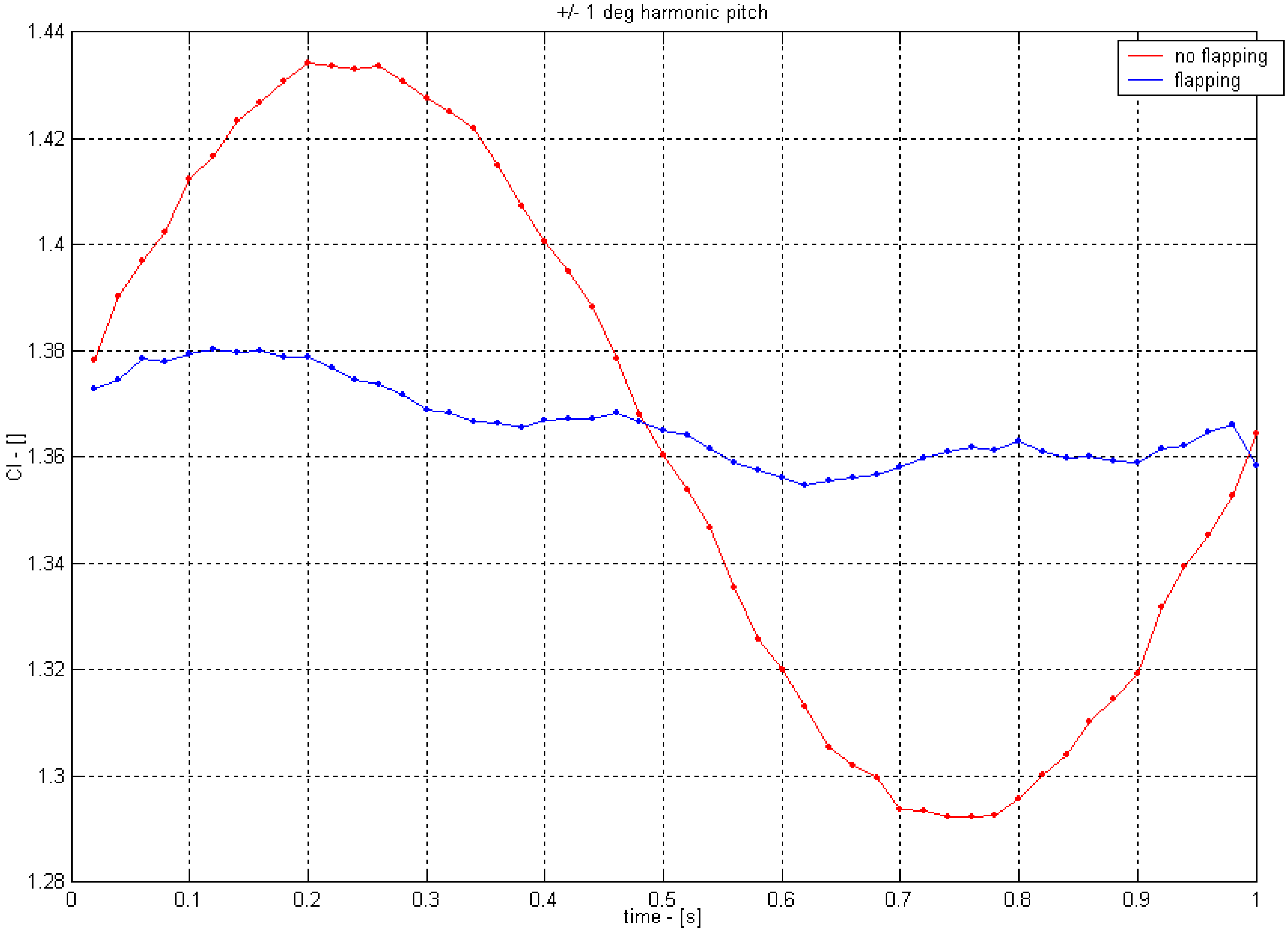


Preliminary result (step flap)





Preliminary result (pitch + flap)



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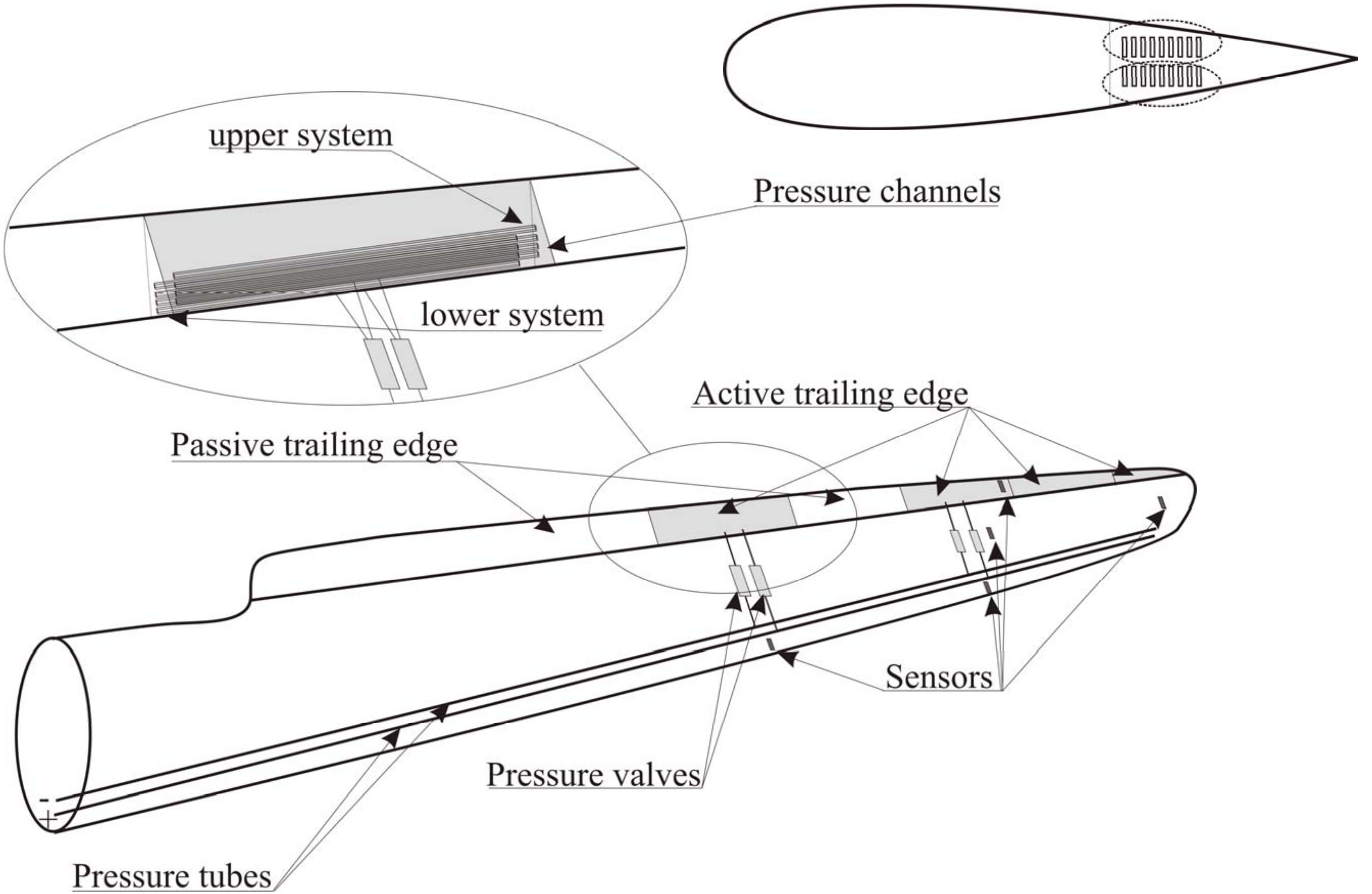
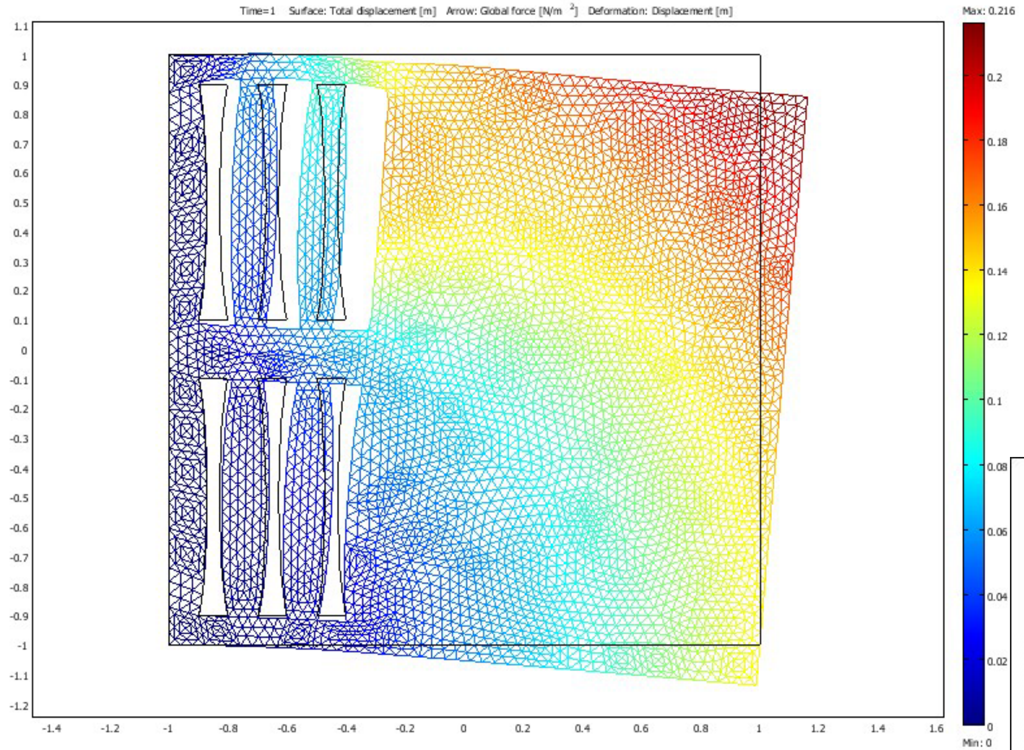
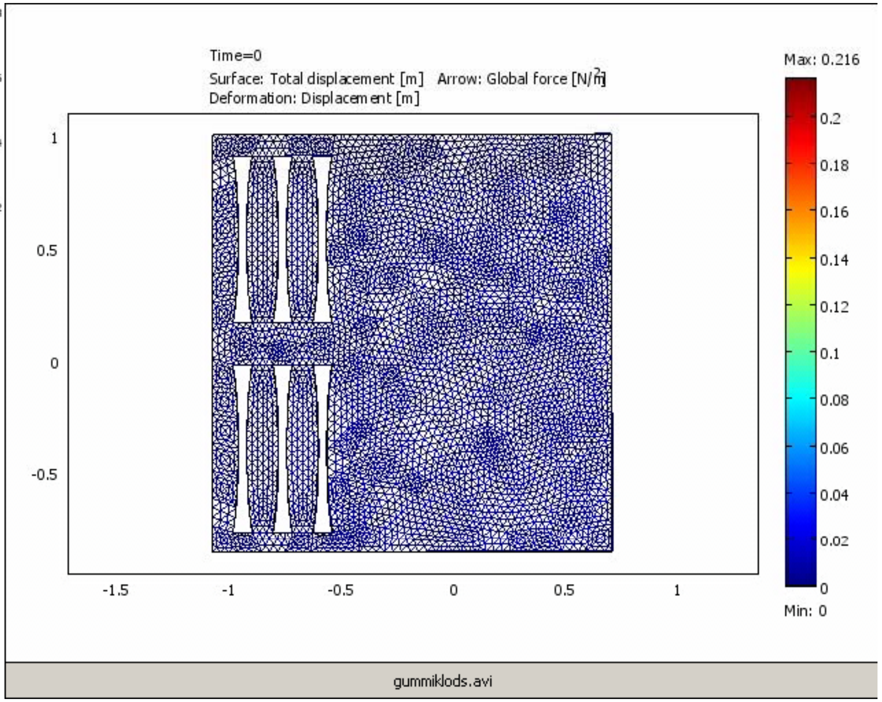
The system





Time=1 Surface: Total displacement [m] Arrow: Global force [N/m 2] Deformation: Displacement [m]
Max: 0.216
Min: 0



Time=0
Surface: Total displacement [m] Arrow: Global force [N/m2]
Deformation: Displacement [m]
Max: 0.216
Min: 0
gummiklods.avi

Conclusions

- Big (huge?) load reduction potential
- Time-delays in the system should be avoided at all costs
- Fast actuation velocity important
- Preliminary wind tunnel results look very promising: TE could cancel out lift variations from +-1° pitch motion

Future (and present) work

- Sensoring technique (how to determine the state of the wing dynamically)
- Combined pitch and flap control
- Model aerodynamic dynamic stall effects
- Implement into HAWC2
- What are the implications of this stuff on dynamic stability
- More wind tunnel testing
- More realistic situations (whole span same flap control etc.)